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Value at Risk and Inventory Control

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Value at Risk and Inventory Control

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Abstract :
The purposes of this paper are two-fold. On the one hand, we shall provide a decision analysis justification for the Value at Risk (VaR) approach based on ex-post, disappointment decision making arguments. We shall show that the *VaR* approach is justified by a disappointment criterion. In other words, the asymmetric valuation between ex-ante expected returns above an appropriate target return and the expected returns below that same target level, provide an explanation for the VaR criterion when it is used as a tool for VaR efficiency design. Second, this paper provides applications to inventory management based on VaR risk exposure. Although the mathematical problems arising from an application of the VaR approach, tuned to current practice in financial risk management, are difficult to solve analytically, solutions can be found by application of standard computational and simulation techniques. A number of cases are solved and formulated to demonstrate the paper's applicability.

Keywords : *Inventory ; VaR, disappointment*

Résumé :
Cet article a deux buts. D'une part de développer une justification a la décision basée sur l'application du VaR (Value at Risk) se basant sur des critères de décision ex-post de "déception" . Nous montrons ainsi que le VaR implique une valeur asymétrique des risques formulée en termes de déception ex-post par rapport a des résultats espérés et attendus. Deuxièmement; cet article applique une notion d'efficience de VaR à la gestion des stocks sensible aux critères de risques impliqués par le VaR. Bien que des résultats analytiques à la solution des problèmes définie est généralement difficile; il est possible d'utiliser pratiquement des techniques de calcul numérique et de simulation. Quelques exemples sont résout permettant une appréciation de l' approche VaR aux problèmes de risques de type industriels.

Mots-clès : Stocks, VaR, Déception

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Introduction

Traditionally, inventory control has emphasized an ex-ante rather than an ex-post approach. In practice, however, time phasing of information and the inventory decision-making process combine to render most theoretical models of limited usefulness. For example, supply flexibility, supply delays management and related issues may often be the determinant factors in adopting an appropriate policy that is sensitive to demand and other uncertainties. These problems recur in many forms. In the economic literature it appears under the irreversibility effect and option value (Kreps, 1979, Freixas, 1987), although they are rarely applied in inventory control (for an exception see Ritchken and Tapiero 1986 for the use of options in inventory control with price and demand uncertainty). Further, the traditional approach to measuring costs in inventory management has been oblivious to revenues generated by maintaining inventories on the one hand and to the difficulties encountered when shortage costs must be assessed. Costs such as, “goodwill”, managerial attitudes towards losses and regrets (compared to “reaching the right decision”) and so on, are hardly quantifiable and therefore mostly neglected.

Further, traditional inventory models have been based essentially on the minimization of expected costs--both direct and indirect ones, neglecting thereby managers' risk preferences. Such preferences exist, expressed by manager's avoidance to perform out of target cost performance, where under-performing may induce particular penalties. These last few years, financial managers have used increasingly VaR (Value at Risk) as a means to measure and manage risk exposure and at the same time hedge trading and other financial policies. VaR is defined as the expected loss arising from an adverse market movement with specified probability over a period of time. For financial institutions for example, a certain amount of capital (a reserve) must then be set aside so that the probability that the institution will not survive adverse market conditions remains very small (see Jorion, 1996, 1997 and Duffies and Pan, 1997 for an exposition of this subject). In a similar sense, in inventory control “a certain amount of stock is built up” so that adverse effects, due to random demands, price uncertainties and other risks generating excessive costs are balanced. However, while the inventory approach is focused on managing inventories (a physical good), the VaR approached is focused on managing money. The contribution of this paper is then to focus on the management of inventory through the management of the "money" tied up in inventory or the moneys implied in inventory shortcomings.

Although VaR is currently broadly used, it has some critiques. For example, Arztner, Delbaen, Heber and Heath (2000) have shown that VaR should not be used as the sole measure of risk exposure since it does not satisfy all the properties needed from a risk measure. Technically, VaR is defined for a given time horizon T and a confidence level p (denoted by P_{VaR}) by the loss in market value that is exceeded with probability $(1-P_{VaR})$. In other words, it is the probability of loosing, say x, which is greater than Φ over a period of time (horizon) T, or:

$$P(x < -\Phi) = \int_{-\infty}^{-\Phi} P_T(x)dx$$

where $P_T(.)$ is the probability defined over the time period T. Thus, the VaR probability is:

$$P_{VaR} = \int_{-\infty}^{\Phi_{VaR}} P_T(x)dx$$

Thus, the purposes of this paper are two-fold. First, we provide a justification for the Value at Risk approach based on ex-post, disappointment decision-making arguments (see also Bell 1982, 1983, 1985, Gul 1991, Tapiero, 2000). In other words, an asymmetric valuation between ex-ante expected costs above an appropriate target cost and the expected costs below that same target level, provide an explanation for the VaR criterion when it is used as a tool for VaR efficiency design. Such an approach provides also some insights regarding the selection of the probability P_{VaR} which is usually specified by management. This probability turns out in our case to be the ratio of the asymmetric linear cost parameters. Second, the paper solves a specific problem based on VaR risk exposure in inventory management and shows how inventory policy can be designed to express inventory manager's concern for their "money and risk" preferences. We also show that single period, multi-periods, multi products inventory problems as well as inventory with price and demand uncertainty (Ritchken and Tapiero 1986) can be considered using the standard VaR approach. Although the mathematical problems arising from such applications of the VaR approach are difficult to solve analytically, solutions can be found by application of standard computational and simulation techniques.

This paper's approach thus differs substantially from the traditional approach to inventory control. In textbooks-like inventory problems the optimum order quantity is targeted and determined by minimizing expected cost, resulting in an optimal quantile risk constraint to be maintained by the inventory order policy. In this paper however, we target an inventory investment policy and use (as in inventory control) a linear and asymmetric costs associated to deviations from the optimal targeted costs. Least cost optimization leads as well to a quantile risk providing a value at risk constrained by the manager's preferences. This value at risk is then optimized in a second stage to determine the optimal inventory policy which is compatible with managers' preferences implied by the quantile risk constraint. In this sense, our approach to inventory control is sensitive to both the cash disbursements and the uncertain costs the inventory manager deals with and his asymmetric preferences for under or over performing an optimal inventory investment.

2. VaR. Deception-Regret and Inventory Control

Savage (1954) regret criterion has inspired a number of approaches coined “regret-disappointments models” (Loomes and Sugden 1982, 1987). According to Bell 1982, disappointment is a psychological reaction to an outcome that does not meet a decision maker expectation. Ex-post optimization would thus imply the minimization of disappointments. Bell in particular, assumes that the measurement of disappointment is proportional to the difference between expectation and the outcome below the expectation. Elation occurs when the outcome obtained is better than its expectation. A general treatment is provided by Jia and Dyer 1994. The “value asymmetry” between “elation” and “regret-loss” are fundamental issues reckoned with in decision theory. Bell for example, points out that the “cost of reaching the wrong decision” may be, proportionately, greater than the payoff of having made the right decision. In other words, managers abhor losses, valuing them more than they value the gains obtained by making the ex-post right decision. This explains a preference for flexibility not justified by the use of expected costs. For example, the contingent ability to supply a customer from a competitor’s inventory might be worth more than the expected benefit gained from such a transaction. Similarly, the ability to meet customers demand without “showing excessive inventories” is also valuable to inventory managers who abhor holding inventory—for it “advertises” poor planning decisions. The Value at Risk approach provides an expression for these considerations which has not been sufficiently elaborated on. Further, a specification of parameters in VaR applications have economic effects and meanings that are not easily justified. Given such parameters (P_{VaR}, VaR), they can be used to prioritize policies (whether in selecting portfolio, managing inventory risks or in dealing with risk management problems in general). Our VaR application to inventory management is a novel approach to dealing with risk exposure and in designing inventory policies concurrent with a predetermined level of risk exposure expressing inventory manager's risk preferences. To see how this is done, we consider a text-book inventory control problem and establish its relationship with well known results in inventory management.

3. Inventory VaR Management

Consider a single period and say that a firm costs originating in the management of inventories, say z, is a random variable which we denote by $\tilde{C}(z)$. Let Q be some value, say a planned or targeted cost, above which costs are valued linearly, proportionately to some factor a and below which, costs are valued linearly proportionately to some other factor b. Thus, given the asymmetric valuation of losses (measured as a deviation from an appropriate target to be calculated), we assume an objective which consists in the selection of the optimal target Q given by the minimization of deviations from this goal (see also Gul 1991):

$$\Phi = b\,E\left[\tilde{C}(z) - Q \,\middle|\, \tilde{C}(z) \geq Q\right] + a\,E\left[Q - \tilde{C}(z) \,\middle|\, \tilde{C}(z) \leq Q\right]; \quad b \geq a$$

We can rewrite this expression in a form reminiscent of goal programming procedures:

$$\Phi = E\left\{b\left[\tilde{C}(z) - Q\right]^{+} + a\,E\left[Q - \tilde{C}(z)\right]^{+}\right\};$$

Explicitly, this is given by:

$$Min\,\Phi_Q = b\int_{Q}^{\infty}\left(\tilde{C}(z) - Q\right)dF_C + a\int_{-\infty}^{Q}\left(Q - \tilde{C}(z)\right)dF_C;$$

The solution for one period is therefore:

$$-b(1-F_C(Q))+aF_C(Q)=0 \text{ or } F_C(Q)=\frac{b}{(b+a)}; b>a$$

$$F_C(Q)=P_{VaR} \text{ with } P_{VaR}=\frac{b}{b+a} \text{ and } Q(z)=F_C^{-1}\left(z;P_{VaR}\right)$$

This equation means that optimal inventory cost target, expressed by the Value at Risk Q, can be expressed equivalently by the specified risk P_{VaR} and the cost (inventory) distribution. In this sense, P_{VaR} implies a preference for a cost policy below the goal Q--the largest loss a firm is willing to sustain. The application of this problem to inventory management is now straightforward, although it can be analytically cumbersome. Assume for simplicity a normal distribution for inventory costs $\tilde{C}(z)$ with mean $E\tilde{C}(z)$ and variance $\text{var}(\tilde{C}(z))$. Then Q can be interpreted as the Value at Risk of an underlying inventory policy and given by:

$$Q(P_{VaR})=VaR(P_{VaR})=E(\tilde{C}(z))+Z_{1-P_{VaR}}\sqrt{\text{var}(\tilde{C}(z))},$$

where $1-P_{VaR}$ is the quantile level of the standard normal distribution. The optimal inventory policy providing the least VaR is then found by solving:

$$VaR^*=\underset{z\geq 0}{Min}\ VaR(P_{VaR}),$$

where z is the optimal starting inventory. Interestingly, Value at Risk minimization is in this case, equivalent to quadratic utility profit maximization where the "index of risk aversion" is equal to $Z_{1-P_{VaR}}$, the risk specification quantile. The optimal inventory policy resulting from minimizing the VaR is a straightforward exercise however. We consider an example to highlight these calculations and obtain a numerical assessment of the problem at hand. Subsequently, we discuss a number of extensions as well as a number of clarifications that allow our approach to be applied to a broad number of situations in inventory control.

Example: An Inventory Cost Problem

Define a standard one period stochastic demand inventory model with linear cost $\tilde{C}(z)=cz+h\max(z-\tilde{x},0)+v\max(\tilde{x}-z,0)$ with c—the ordering cost, h—the holding cost and v—the shortage cost. The demand is given by the random variable $\tilde{x}\geq 0$.

Assume as a first approximation that costs have a normal probability distribution. Straightforward calculations point out to the following first two moments:

$$E\left(\tilde{C}(z)\right) = cz + z(h+v)F_x + v(\hat{x} - z) - (h+v)F_{1,x}$$

$$Var(\tilde{C}(z))^2 = E\left[cz + h\ \max(z - \tilde{x}, 0)\ + v\max(x - z, 0)\right]^2 - \left[E(\tilde{C}(z))\right]^2$$

where the variance is explicitly given by:

$$Var(\tilde{C}(z)) = -z^2(v-h)(h+v+2c)F_x - (v^2 - h^2)F_{2,x} + 2z(v-h)(h+v+c)F_{1,x}$$

$$-(h+v)^2\left(zF_x - F_{1,x}\right)^2 + 2(h+v)\left(z(v-c) + v\hat{x}\right)\left[zF_x - F_{1,x}\right] + v^2\left[E(x^2) - \hat{x}^2\right]$$

with

$$F_x(z) = \int_0^z dF_x(\tilde{x});\quad F_{1,x}(z) = \int_0^z \tilde{x}\ dF_x(\tilde{x});\quad F_{2,t}(z) = \int_0^z \tilde{x}^2\ dF_x(\tilde{x})$$

For a given inventory cost distribution, the least value at risk is:

$$Min\Phi_Q = b\int_Q^\infty \left(\tilde{C}(z) - Q\right)dF_C + a\int_{-\infty}^Q \left(Q - \tilde{C}(z)\right)dF_C;$$

yields $F_C(Q) = l$, $l = b/(b+a)$ or $P_{VaR} = l$ and therefore it is a function of the inventory policy z, $Q(z) = F_C^{-1}\left(z; P_{VaR}\right)$. The least VaR inventory policy is thus reduced to selecting the inventory ordering policy that minimizes the value at risk:

$$VaR^* = \underset{z\geq 0}{Min}\left\{E\tilde{C}(z) + Z_{1-P_{VaR}}\sqrt{Var(\tilde{C}(z))}\right\},$$

Of course in traditional inventory models, the expected cost only is usually minimized while in the VaR approach costs standard deviation is also considered, accounting for decision makers risk attitude and preference (explicitly weighted by the $Z_{1-P_{VaR}}$ factor). Assuming an interior solution, the optimal ordering inventory policy is found by solving:

$$\frac{\partial E\tilde{C}(z)}{\partial z} = -\frac{1}{2}Z_{1-P_{VaR}}\frac{1}{\sqrt{\mathrm{var}(\tilde{p}(z))}}\frac{\partial\,\mathrm{var}(\tilde{C}(z))}{\partial z}$$

Note that expected minimization leads to $\dfrac{\partial E(\tilde{C}(z))}{\partial z} = c + (h+v)F_x - v$ and thereby to the traditional inventory result: $\partial E(\tilde{C}(z))/\partial z = 0$, well known in single period inventory cost problems and leading to an optimal shortage probability given by

$1-F_x(z)=(h-c)/(v+h)$. When we consider the VaR minimization however, we first note that:

$$\frac{\partial \operatorname{var}(\tilde{C}(z))}{\partial z}=2z[c+\mathrm{v}]^2-2v(v+c)\hat{x}-2(v-h)\left[z(h+v+2c)F_x+(h+v+c)F_{1,x}\right]-$$
$$-2E(\tilde{C}(z))\frac{\partial E(\tilde{C}(z))}{\partial z}$$

which can be used to calculate the VaR sensitive optimal inventory policy. Although an analytical solution is cumbersome, a numerical one can be found easily. For example, if we assume the following cost parameters: c=0, h=1, v=3 and the demand has a uniform probability distribution in $[0,M]$ with $M=100$, then:

$$Var(\tilde{C}(z))=-8\mathrm{z}^2F_x-8F_{2,x}+16zF_{1,x}+9\left[E(x^2)-\hat{x}^2\right]$$
$$-16\left(zF_x-F_{1,x}\right)^2+8\left(3z+\hat{x}\right)\left[zF_x-F_{1,x}\right]$$

$$\mathrm{F}_x(z)=\frac{\mathrm{z}}{M};\quad \mathrm{F}_{1,x}(z)=\frac{z^2}{2M};\mathrm{F}_{2,x}(z)=\frac{z^3}{3M}$$

and

$$Var(\tilde{C}(z))=\frac{3M^2}{4}+\frac{\mathrm{z}^2}{6}+\frac{28\mathrm{z}^3}{3M}-\frac{4z^4}{M^2}=\frac{30000}{4}+\frac{\mathrm{z}^2}{6}+\frac{28\mathrm{z}^3}{300}-\frac{4z^4}{10000}$$

leading to:

$$\frac{\partial Var(\tilde{C}(z))}{\partial z}=\frac{\mathrm{z}}{3}+\frac{7\mathrm{z}^2}{25}-\frac{8z^3}{5000}>0\,.$$

With these results on hand, it is simple to calculate the optimal inventory policy by numerical means. For the following values of $Z_{1-P_{VaR}}$ =(0;0.05;0.1;0.15;0.2) for example, we found that the optimal order quantities are: (75; 78.11; 81.26; 84.42; 87.58) respectively. The difference 78.11-75=3.11 in particular measures the risk premium an inventory manager pays for a quantile risk specification $Z_{1-P_{VaR}}=0.05$. A doubling of this risk specification induces a risk premium of 6.26 however. These are expected results, since a greater intolerance of risk induces the willingness to pay a larger premium for inventory holding. For comparison, note that in the expected cost case, we have an optimal order quantity of 75. In other words, a Value at Risk inventory policy is in this case more conservative than the traditional inventory policies derived by expected cost minimization.

Conclusion and Extensions

Applied inventory management is beset by far more uncertainties and complexity than simple demand uncertainty models presume. In these cases, inventory models based on expected cost minimization are misleading for they might not recognize the interaction effects of both the multiple sources of uncertainty and complexity inventory may be subjected to. For this reason, problems involving considerations of supply delays, prices, multiple time periods and multiple products, are extremely difficult and of limited practical usefulness. The VaR approach may provide a unified risk and uniform approach to dealing with these problems, either in developing VaR efficient inventory policies or in using the Value at Risk as a constraint specified by risk requirements providing a set of constraints inventory managers are facing. In other words, a coherent risk specification imposed on the inventory policy, regardless of the uncertainties and the complexity of the inventory model, may provide a practical and consistent approach to inventory control. To conclude, we discuss and provide a number of such models that apply this approach. Computational issues are ignored, although and ex-post optimization and simulation can be used to provide explicit solutions to specific models and problems.

Multi-Period Problems: A uniform risk specification can be used to for multi-periods problems as well. Let $\tilde{C}_{t+1}(S_t)$ be the costs generated at time t+1 by an inventory policy denoted by S_t and initiated at time t for the period $[t,t+1)$ and let Q_t be the inventory investment-cost target for time t+1, deviations from which induce a cost. Thus, the inventory VaR at time t is defined by: $VaR_t(S_t)=\tilde{C}_{t+1}(S_t)-Q_t$. As a result, the period risk specification is, as seen earlier, found by minimizing:

$$\underset{Q_t}{Min}\ \mathrm{E}\left\{b\left(\tilde{C}_{t+1}(S_t)-Q_t\right)^{+}+b\left(\tilde{C}_{t+1}(S_t)-Q_t\right)^{-}\right\}$$

leading to a constant temporal risk constraint:

$$P_t\left[VaR_t(S_t,P_{VaR})\le\tilde{C}_{t+1}(S_t)\right]=P_{VaR}=\frac{b}{a+b}$$

Of course, for a normal approximation: $\tilde{C}_{t+1}(S_t)\ \square\square\ \left(m_t(S_t),\Omega_t(S_t)\right)$ with estimated mean $m_t(S_t)$ and variance, $\Omega_t(S_t)$ determined by the inventory sources of uncertainties and the inventory model's complexity. As seen above, the VaR is:

$$VaR(S_t, P_{VaR}) = m_t(S_t) + Z_{1-P_{VaR}}\sqrt{\Omega_t(S_t)} \quad .$$

As a result, an inventory policy can then be defined by a specified P_{VaR} maintained consistently over time while the inventory policy is chosen to maintain such a risk specification. Note that such a problem is still a one period problem since there are no carry over effects.

For example, for a periodic review model starting at time t with: s_t with a quantity on hand I_t at the beginning of the period, an optimal order quantity, instantaneously delivered $u_t = \max(s_t - I_t, 0)$ at a buying price: p_t. The inventory cost in the period is:

$$\tilde{C}_{t+1}(S_t) = -\tilde{p}_t \max(\tilde{x}_t, s_t) + \left[p_t \max(s_t - I_t, 0) + c_t \max(s_t - \tilde{x}_t, 0) + v_t \max(\tilde{x}_t - s_t, 0) \right]$$

Where revenues during the period are $\tilde{p}_t \max(\tilde{x}_t, s_t)$, $\tilde{x}_t$ is the random quantity demanded during the period. Inventory carrying charges and lost sales due to shortages are also accounted by the following (standard) costs:

$$c_t \max(s_t - \tilde{x}_t, 0) + v_t \max(\tilde{x}_t - s_t, 0)$$

where c_t, v_t are appropriately defined parameters. Finally, lost sales, at time t, are:

$$I_t = \max(s_{t-1} - x_{t-1}, 0)$$

Note that at time t, the buying price, the order quantity and beginning inventory are known while in a multi-period context future prices and future initial stocks are also random. Further, in a multi period problem, call on real options on the future acquisition of supplies (both expressed by the quantity acquired and the price) may be considered, adding another financial dimension to our inventory problem (see also Ritchken and Tapiero, 1986 who have shown that this is economical whenever there is a joint uncertainty in demand and prices).

Say that we define a constant VaR^* for the inventory investment, to be met each time period. Then, the optimal inventory policy for multiple time periods is VaR (risk) consistent if:

$$\underset{0 \le s_t,\ t=0,1,2,3...}{VaR_t}(S_t; P_{VaR}) \le VaR^*$$

Such a policy is also optimal if the Value at Risk is also minimized as we saw earlier. For a normal approximation, the inventory policy each time period is found by minimizing the Value at Risk and solving for S_t in:

$$m_t(S_t) + Z_{1-P_{VaR}}\sqrt{\Omega_t(S_t)} \le VaR^*$$

where:

$$m_t(S_t) = E\tilde{C}_{t+1}(S_t) = -\int_{\tilde{p}_t\in\Pi}\int_0^{s_t}\tilde{p}_t\tilde{x}_t dF_{\tilde{p},\tilde{x}} - s_t\int_{\tilde{p}_t\in\Pi}\int_{s_t}^{\infty}\tilde{p}_t dF_{\tilde{p},\tilde{x}} +$$
$$+\left[\int_{p_t\in\partial}\tilde{p}_t\max(s_t - I_t, 0)dF_{p_t} + c_t\int_{-\infty}^{s_t}(s_t - \tilde{x}_t)dF_x + v_t\int_{s_t}^{\infty}(\tilde{x}_t - s_t)dF_x\right]$$

while the variance is calculated by the usual methods.

VaR consistency over time can also be met by specifying it as a temporal constraint and minimizing expected costs. In this case, our problem is:

$$\underset{0\le s_t,\ t=0,1,2,3...}{Min} E\sum\tilde{C}_{t+1}(S_t) \ \ Subject\ to: \ \ VaR_t(S_t; P_{VaR}) \le VaR^*$$

which we can write explicitly for a normal approximation by:

$$\underset{0\le s_t,\ t=0,1,2,3...}{Min} \sum m_t(S_t) \ \ Subject\ to: m_t(S_t) + Z_{1-P_{VaR}}\sqrt{\Omega_t(S_t)} \le VaR^*$$

which is a nonlinear optimization problem we can solve numerically.

VaR, Scenario based Optimization and Stochastic Goal Programming: When normal (or other probability) approximations are not realistic, the approach outlined here can be used to accommodate practical and scenario based data. To do so, we can use the "stochastic goal programming framework" to determine the optimal VaR. In this case, the VaR efficient policy is found by solving:

$$\underset{Q_t, 0\le s_t, t=0,1,2,3...}{Min} E\sum P_{VaR}\left(\tilde{C}_{t+1}(S_t) - Q_t\right)^+ + (1-P_{VaR})\left(\tilde{C}_{t+1}(S_t) - Q_t\right)^-$$

For a specific inventory policy and M cost scenarios, we have the following M deterministic optimization problems:

$$\underset{Q_t, 0\le s_t, t=0,1,2,3...}{Min} \sum_{t=0} P_{VaR}\left(C_{j,t+1}(S_t) - Q_t\right)^+ + (1-P_{VaR})\left(C_{j,t+1}(S_t) - Q_t\right)^-$$

which can be transformed as follows:

$$\underset{Q_t, 0 \le s_t, t=0,1,2,3...}{Min} \sum_{t=0} P_{VaR} u_{jt} + (1 - P_{VaR}) v_{jt}$$
$$u_{jt} - v_{jt} = C_{j,t+1}(S_t) - Q_t$$
$$0 \le u_{jt} = \left(C_{j,t+1}(S_t) - Q_t\right)^+ ;$$
$$0 \le v_{jt} = \left(C_{j,t+1}(S_t) - Q_t\right)^-$$

Note that in this case, both the Value at Risk and the optimal inventory policy are determined at the same time. Further, the cost estimates generated by each scenario are purposely maintained as general functions. Given these solution, a robust optimization approach can be used to selecting the optima policy.

The problems treated above can of course, be generalized easily to multiple products as well as handle other (non normal) distributions and approximations without amending the basic problem framework. For example, if the normal return assumption is overly optimistic, it might be possible to use some other distribution or provide some approximations based on sample simulations the inventory investment return (see Haim Shore, 1986, 1994, 1995, for such approximations).

Finally, an underlying justification of the paper's approach is that, inventory risk analysis (as well as risk analysis of other operational problems such as maintenance, spare parts management, reliability, quality and many other problems where risk is of essential concern) will be better understood and applied if it uses a terminology and principles commonly accepted by risk and financial managers. The Value at Risk approach to operational risk provides one such avenue we can follow as shown in this paper.

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ABSTRACT

The purposes of this paper are two-fold. On the one hand, we shall provide a decision analysis justification for the Value at Risk (VaR) approach based on ex-post, disappointment decision making arguments. We shall show that the VaR approach is justified by a disappointment criterion. In other words, the asymmetric valuation between ex-ante expected returns above an appropriate target return and the expected returns below that same target level, provide an explanation for the VaR criterion when it is used as a tool for VaR efficiency design. Second, this paper provides applications to inventory management based on VaR risk exposure. Although the mathematical problems arising from an application of the VaR approach, tuned to current practice in financial risk management, are difficult to solve analytically, solutions can be found by application of standard computational and simulation techniques. A number of cases are solved and formulated to demonstrate the paper's applicability.

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